Fermilab

UPC No. 109

BEND MAGNET QUADRUPOLE COMPONENT

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August 20, 1979

We present results of a Monte Carlo type calculation on the effect of a randomly distributed normal quadrupole term in each dipole on the extraction process.

The important quadrupole harmonics for the extraction system are 0th harmonic (machine tune), sine-like and cosine-like phase of the 39th harmonic. A quadrupole term in the dipoles will effect all of these three harmonics and must be negated by using the correction coil package. The details of the calculation we have made are as follows: first the "normal" lattice using the design field magnets and two high-beta long straight sections is set up with a horizontal tune of 19.45. To each dipole a random quadrupole term is added to the other high order harmonics. The quadrupole terms are generated in a Gaussian distribution with a zero mean and a standard deviation of 1.0×10^{-3}/in., no cut off on the tails of the distribution is made (i.e., we do not reject bad magnets) and no attempt is made to arrange the sequence of magnets to avoid bad groups

The current magnet selection criteria require that the quadrupole term, b1, lie in the range $\pm 2.5 \times 10^{-4}$/in. so we are creating a situation which is at least a factor of 4 worse than that which we can hope to find in the Tevatron.

Using a small off-momentum closed orbit ($\Delta p/p = 0.05\%$) on which the higher order odd harmonics do not completely cancel we then measure the tune of this "new" machine by perturbing the orbit slightly. An appropriate change is then made to the quadrupole bus current to bring the measured tune back to the original value of 19.45.

At this point we then turn on the slow extraction devices and observe the behavior of the phase space trajectory of the separatrix. The extraction devices used for this calculation consist of 8 quadrupoles and octopoles on the cosine-like phase of the 39th harmonic together with 4 quadrupoles on the sine-like phase, both phases being powered independently. The magnet values are then adjusted to correct for changes to the phase angle of the separatrix as well as the rate of growth of the oscillation amplitude. This correction procedure is illustrated in Figs. 1, 2, and 3. Figure 1 shows a normalized phase space plot of the separatrix trajectory made at the extraction Lambertson showing the split between the circulating and extracted beams. This plot is made using the design fields. A similar plot is given in Fig. 2, with the random quadrupole term added to the dipole field but without making any attempt to correct for them. One can see that the phase angle of the separatrix has changed sufficiently that the circulating beam never manages to reach the electrostatic septum. Figure 3 shows the same separatrix after adjusting both phases of extraction quadrupoles to correct for the random field errors.

In order to get some feeling for the possible field strength needed in the correction coil package to cancel the bend magnet quadrupole term, we have performed the above calculation for 10 different random distributions. The results are summarized in Table 1 which gives the field strengths needed for extraction for the different cases.

In we assume that 8 correction coil quadrupoles will be connected to each phase of the 39th harmonic with each quadrupole capable of producing 60 kG-in. then only in one case (VII) would there be insufficient field to completely compensate for the dipoles on the 39th harmonic. The induced tune shifts are an order of magnitude smaller than the requirements imposed by the colliding beams and hence lie well within the range of the correction quadrupoles. As previously mentioned the field errors we have used in these calculations are at least a factor of 4 worse than those we can expect to find in the Tevatron. Consequently we conclude that the correction coil package is completely capable of cancelling the normal quadrupole harmonic present in the dipoles during the extraction cycle.

A further check on the lattice stability is given in Figs. 4 and 5. We have plotted the maximum amplitude of the betatron oscillations (excluding the high-beta long straight sections) attained during the last $1\frac{1}{4}$ turns for the design fields (Fig. 4) and one of the random distributions (Fig. 5). The increase in amplitude during the last turn is evident in both cases, but more specifically Fig. 5 shows no major change in harmonic structure from Fig. 4.

Table 1 - Extraction Quadrupole Field Strengths

Case	Tune Shift	Change in Quad Bus Current To Correct Tune %	39th Harmonic Quad Field Strength kG - in. at 1 in. Cosine-like	Sine-like
I	-0.0119	0.052	286	-136
II	-0.0217	0.1	95	+13.5
III	0.0209	-0.1	245	+41
IV	-0.0076	0.035	205	+27
V	Unstable[a]	-0.23	328	+177
VI	-0.0002	-	314	-273
VII	0.0081	-0.03	546	+300
VIII	-0.0077	0.015	191	-205
IX	Unstable[a]	-0.21	55	-82
X	0.0170	-0.075	96	-48

[a] inside the $\frac{1}{2}$ integer stop band

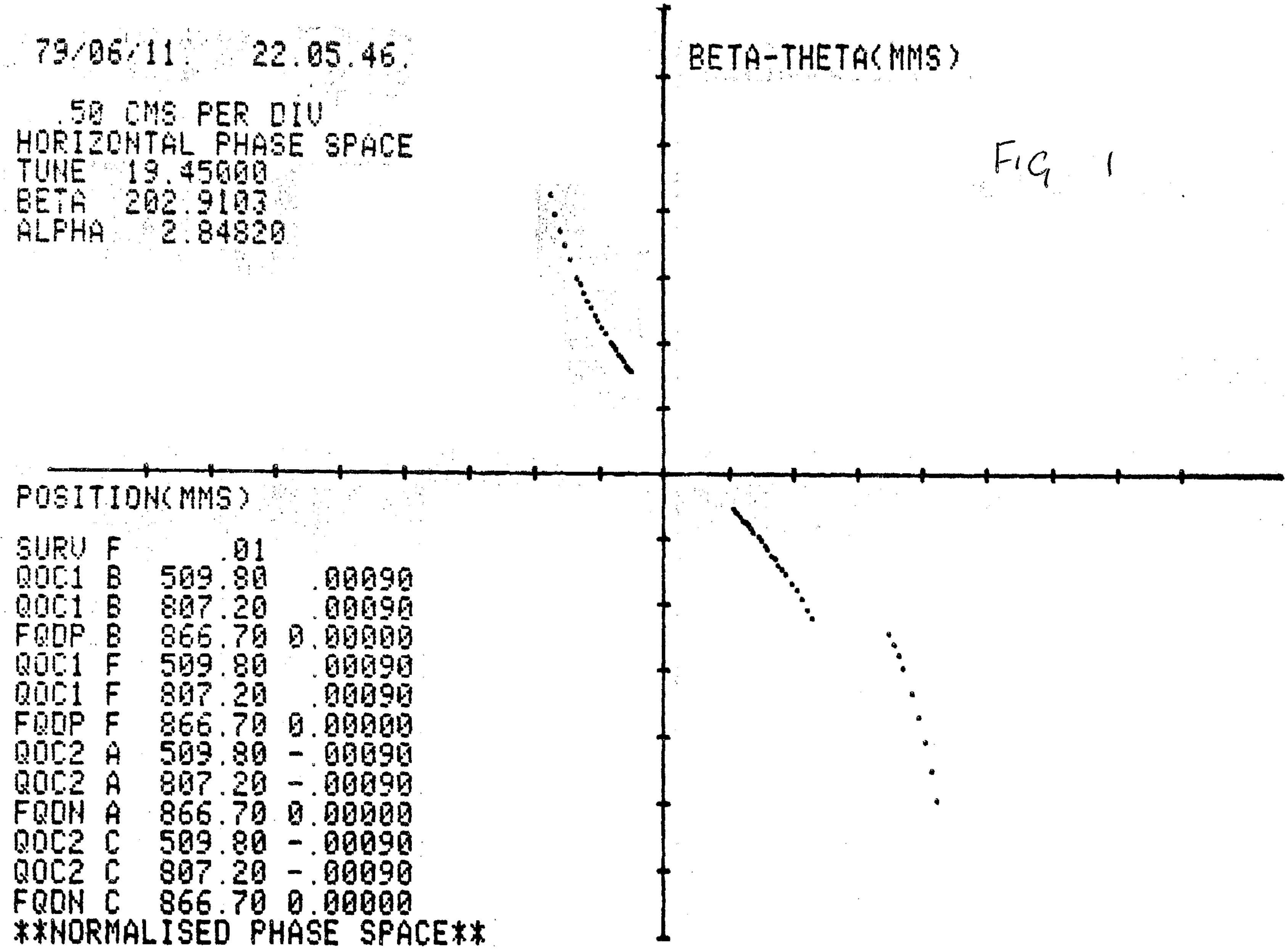
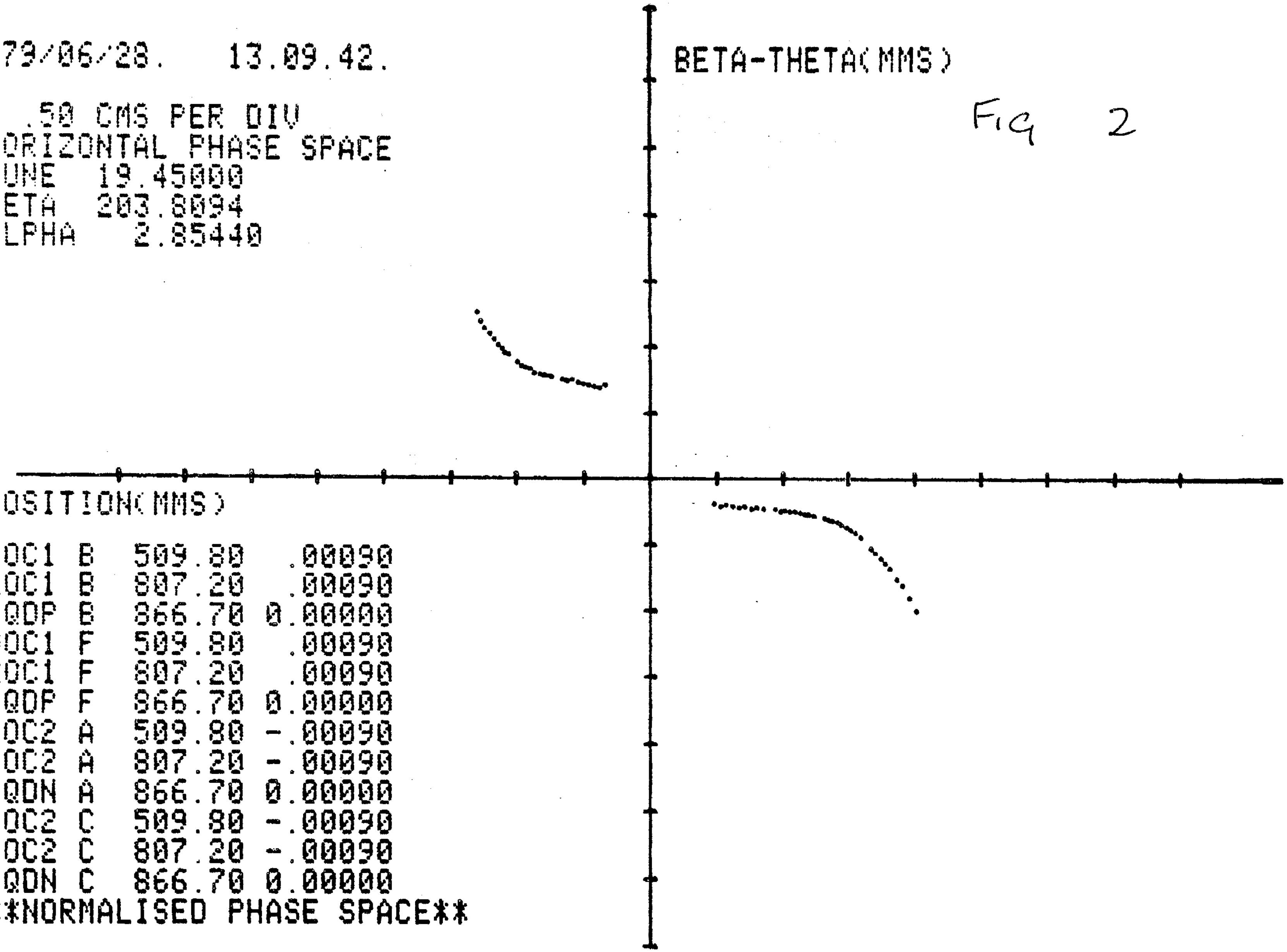

79/06/11. 22.05.46.
.50 CMS PER DIV
HORIZONTAL PHASE SPACE
TUNE 19.45000
BETA 202.9103
ALPHA 2.84820
BETA-THETA(MMS)
POSITION(MMS)
SURV F .01
QOC1 B 509.80 .00090
QOC1 B 807.20 .00090
FQDP B 866.70 0.00000
QOC1 F 509.80 .00090
QOC1 F 807.20 .00090
FQDP F 866.70 0.00000
QOC2 A 509.80 -.00090
QOC2 A 807.20 -.00090
FQDN A 866.70 0.00000
QOC2 C 509.80 -.00090
QOC2 C 807.20 -.00090
FQDN C 866.70 0.00000
NORMALISED PHASE SPACE

FIG 1

Fig 2

79/06/28. 13.09.42.

.50 CMS PER DIV
HORIZONTAL PHASE SPACE
TUNE 19.45000
BETA 203.8094
ALPHA 2.85440



QOC1	B	509.80	.00090
QOC1	B	807.20	.00090
FQDP	B	866.70	0.00000
QOC1	F	509.80	.00090
QOC1	F	807.20	.00090
FQDP	F	866.70	0.00000
QOC2	A	509.80	-.00090
QOC2	A	807.20	-.00090
FQDN	A	866.70	0.00000
QOC2	C	509.80	-.00090
QOC2	C	807.20	-.00090
FQDN	C	866.70	0.00000

NORMALISED PHASE SPACE

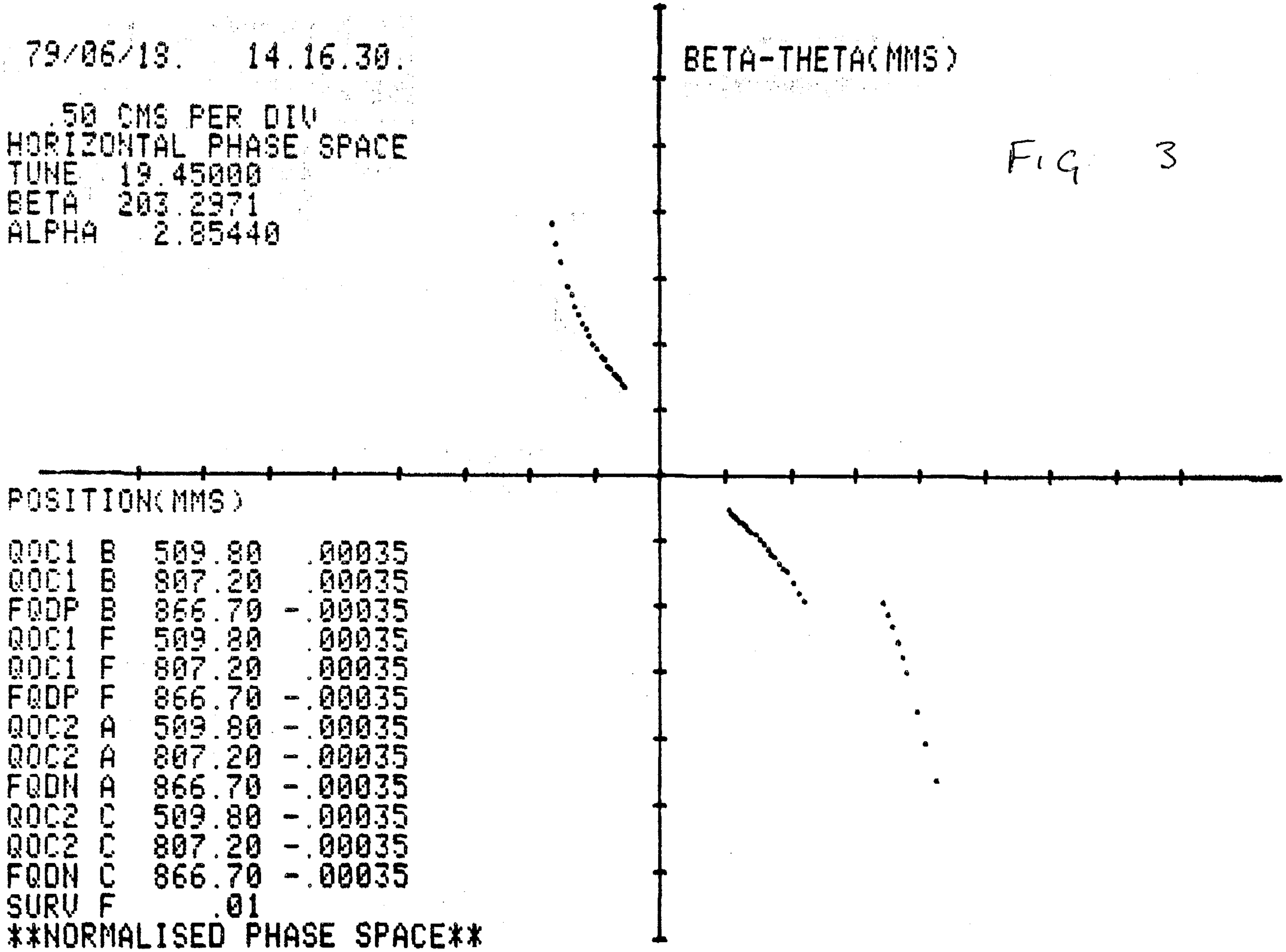
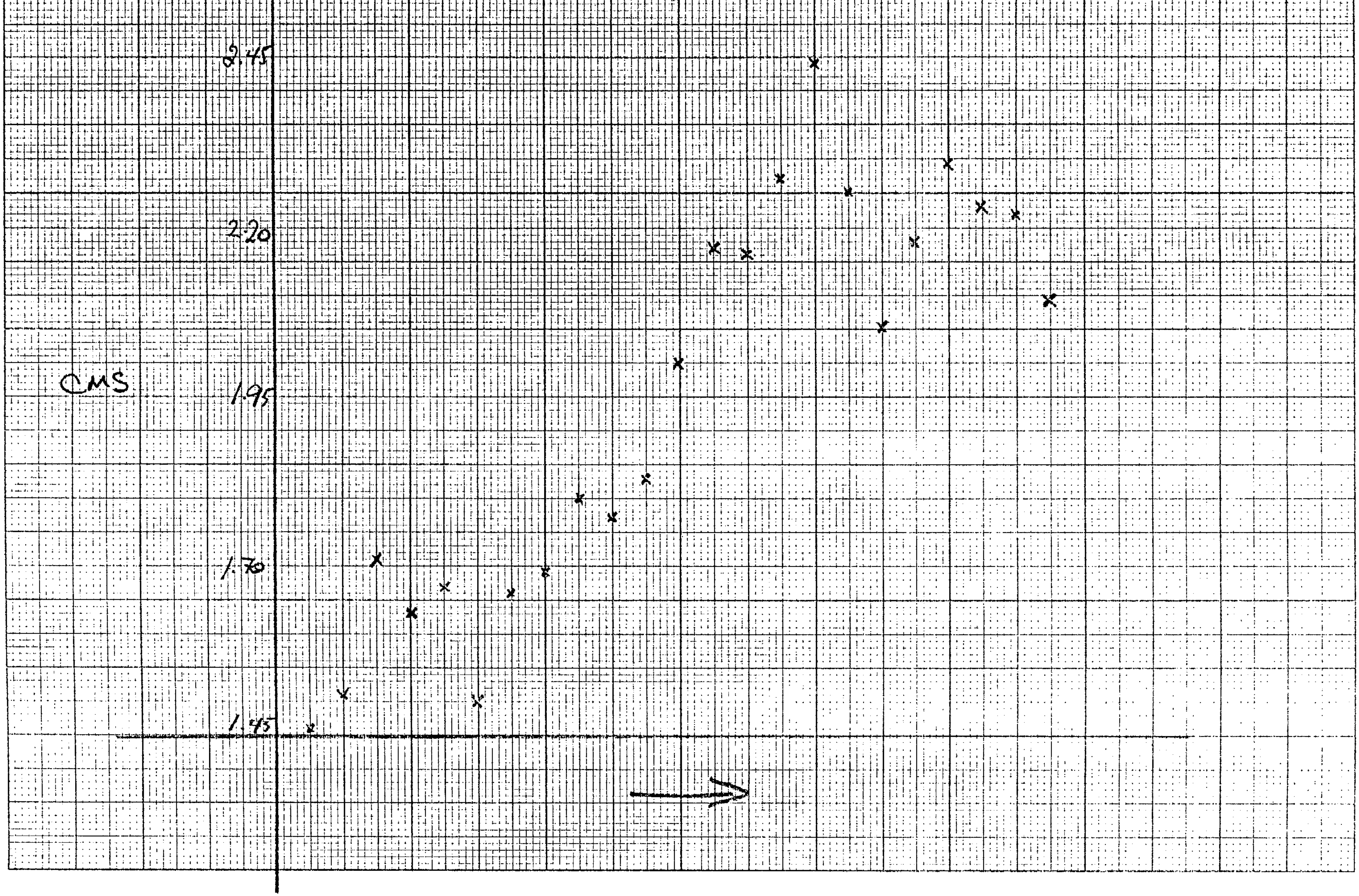
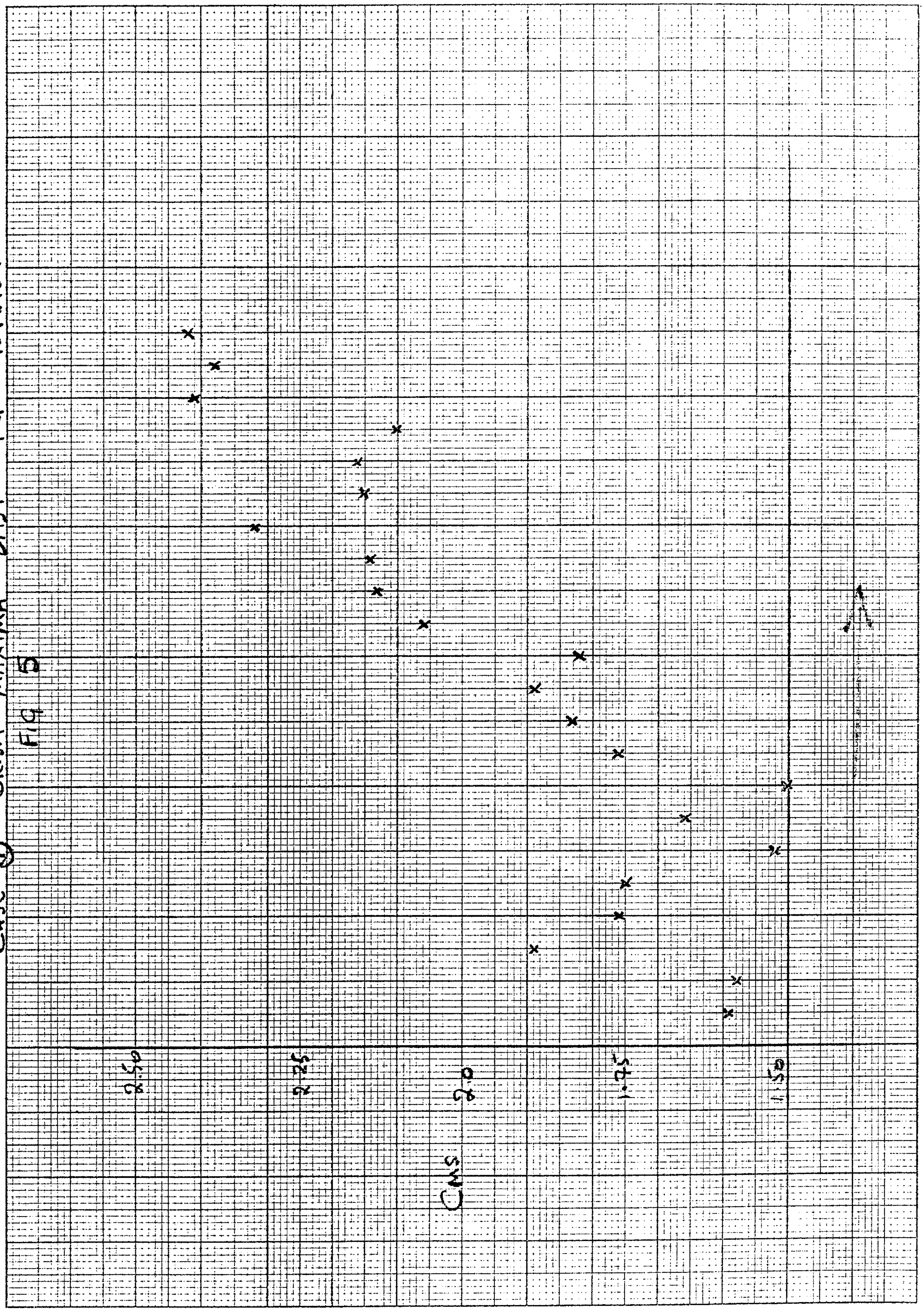

79/06/19. 14.16.30.
.50 CMS PER DIV
HORIZONTAL PHASE SPACE
TUNE 19.45000
BETA 203.2971
ALPHA 2.85440
BETA-THETA(MMS)
POSITION(MMS)
QOC1 B 509.80 .00035
QOC1 B 807.20 .00035
FQDP B 866.70 -.00035
QOC1 F 509.80 .00035
QOC1 F 807.20 .00035
FQDP F 866.70 -.00035
QOC2 A 509.80 -.00035
QOC2 A 807.20 -.00035
FQDN A 866.70 -.00035
QOC2 C 509.80 -.00035
QOC2 C 807.20 -.00035
FQDN C 866.70 -.00035
SURV F .01
NORMALISED PHASE SPACE

Fig 3

"NORMAL" SNOWDON FIELDS QR31T MAXIMA LAST 1¼ TURNS

FIG 4




CASE 1 ORBIT MAXIMA LAST 1¼ TURNS.
FIG 5
2.50
2.25
2.0
1.75
1.50
CMS